U.S. Department
of Transportation

Federal Railroad Administration

Memorandum

Date: April 10, 1996

Rely to Attn of:

Subject: National Plan for Intelligent Transportation System
Highway-Rail Intersection User Service #30

From: Bruce M. Fine
Associate Administrator for Safety

To: Jolene M. Molitoris
Administrator

Enclosed for your approval and signature is a transmittal memorandum and the document "Highway-Rail Intersection User Service". This document establishes the need for including highway-rail crossing safety in the ITS Architecture.

The National Program Plan (NPP) for the Intelligent Transportation System (ITS) is now multimodal. The entire transportation community will benefit by including this User Service in the Architecture. The inclusion and integration of the Highway-Rail Intersection (HRI) with the other ITS initiatives should result in more cost effective crossing safety solutions in the future.

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As a result of the Federal Register announcement at the end of 1994 which sought a broad review of the third draft of the NPP, Mr. Hoy Richards prepared a responsive statement to the Federal Highway Administration's Intelligent Vehicle-Highway System (IVHS) Docket requesting the inclusion of the highway-rail intersection into IVHS (now ITS). Noting that the highway-rail intersection is an intermodal problem and a part of the Traffic Management and Intersection Collision Avoidance Systems for both urban and rural streets, and that the IVHS Architecture ignored this important part of our nation's infrastructure, he recommended the full utilization of ITS technology and the developing road train control infrastructure to improve safety at highway-rail crossings by having it included in the ITS Architecture Development Project. in a separate action, he also prepared and delivered a paper on this subject which became the basis for developing the elements for inclusion.

Recognizing the importance of this recommendation, FRA pursued the matter with FHWA in January 1995. A course of action was explored and it was jointly determined by FRA and ITS JPO that highway-rail intersections are a major safety concern and that resulting critical issues need to be addressed in a stand alone Highway-Rail Intersection User Service. Once prepared, such would become the 30th User Service.

JPO assigned their contractor, Jet Propulsion Laboratory (JPL), to work with FRA and develop a first draft of the "Highway-Rail Intersection User Service #30". This and subsequent drafts were circulated within FRA and externally to various associated railroad industry reviewers, including FH-WA, FTA, several researchers, the AAR and UP Railroad.

More recently, Mr. John Hitz of the Volpe National Transportation Systems Center, under contract to FHWA, provided the final review, assimilation and preparation of the final document enclosed. All reviewers' comments have been addressed and/or included in successive drafts and into the final user service document. This final document is prepared to provide the formal flow of information in the structured architecture format necessary for an ITS User Service. The user service format, which establishes the need and defines a set of system requirements, is in accordance with the ITS system architecture which is the framework that describes how system components interact and work together to achieve total system goals. It is structured to provide information, to different reader groups. The User Service will then be used to develop the Requirements Package by Architecture Development Teams.

The Highway-Rail Intersection (HRI) User Service clearly establishes the highway-railroad crossing, where highways cross rail lines at-grade, as a special case of the highway-highway intersection and, to be fully functioning as a system, must have all system requirements supported, i.e., be integrated with other ITS User Services. It further establishes two subservices: (1) for Standard Speed Rail (SSR) which applies to traditional types of rail operations under 79 mph, and (2) for High Speed Rail (HSR) which applies to rail operations above 79 mph addressing the unique safety requirements imposed by high speed rail service operating in high speed rail corridors. It also addresses how improved highway traffic control and safety could be accomplished through integration of ITS

1.7 **Highway-Rail Intersection User Service**

1.7.1 Introduction

Highway-Rail Intersections (HRI), where highways cross rail lines at-grade, are a special case of Highway-Highway Intersections (HHI). HRI User Service systems will provide improved control of highway and train traffic to avoid or decrease the severity of collisions that occur between trains and vehicles at HRIS. The primary USERS of this service are the highway vehicle driver (motorist) and the train crew responsible for operation of the train (e.g., locomotive engineer). Train types addressed by the HRI User Service include freight, intercity passenger, light rail, and commuter rail. Highway users of this service (collectively referred to, as motorists) include highway transit and emergency vehicle operators, as well as motorcyclists, bicyclists, and pedestrians.

The HRI User Service directly supports the national transportation policy and safety goals as specified in Sections 1010, 1036, and 1072 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the Intelligent Transportation System (ITS) Act of 1991 (incorporated within ISTEA), and the National Highway System Designation Act of 1995. The HRI User Service addresses the National Intelligent Transportation System (ITS) overall goal of improving transportation safety and the specific objectives of reducing the number and severity of transportation accidents, as well as the resulting fatalities and injuries. This service also indirectly supports the goals of enhancing productivity by reducing costs incur-red by fleet and rail system operators and reducing costs to transportation dependent industries.

The HRI User Service provides two major subservices: (1) the Standard Speed Rail (SSR) subservice, which applies to all trains operating at speeds of 79 miles per hour or less; and (2) the High Speed Rail (HSR) subservice, which applies to trains operating at speeds greater than 79 miles per hour. The SSR subservice applies to traditional types of rail service including freight, intercity passenger, light rail, and commuter rail. The HSR subservice is intended to address the unique safety requirements imposed by high speed passenger rail service operating on high speed corridors.

The HRI User Service will reduce the frequency and resulting fatalities and injuries of collisions at HRIs through improved control of train and highway traffic. Improved train control could be accomplished by two basic functions: (1) providing advisories and alarms to train crews of HRI warning device operational status and highway vehicle intrusions onto HRIS; and (2) automated stopping of high speed (greater than 79 mph) passenger trains on designated corridors in rare emergency situations when an obstructing highway vehicle on the HRI can be automatically detected in sufficient time to avoid a collision. Improved highway traffic control could be accomplished through the integration of ITS technologies into a variety of functions including: (1) improved HRI warning devices, (2) roadside variable message signs, (3) in-vehicle motorist advisory, warning, and automatic vehicle stopping, and (4) automated collision notification.

The HRI User Service will be accomplished by the integration of ITS technologies and other ITS User Services with the national network of railroad and highway operations.

The Federal Railroad Administration (FRA) will assist in the development of HRI User

Services within the context of the National ITS Program Plan in close cooperation with the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), and the other participants in the ITS program.

1.7.2 Needs

HRI accidents are one of the most significant safety concerns of railroads and the FRA. In 1994, there were approximately 273,000 HRIs in the United States; 166,000 are public at-grade and 107,000 are private at-grade. Accidents at HRIs occur at a rate of about 4900 each year, resulting in about 600 fatalities and 1900 injuries annually.

Rail traffic volume is increasing to meet the growing demand for efficient intercity passenger and freight service, as well as light rail and commuter rail passenger service. Section 1010 of ISTEA, has also established the need to improve the safety of HRIs to permit the implementation of high speed rail passenger service on a limited number of rail corridors. The Secretary of the U.S. DOT has subsequently designated a number of corridors to provide high speed passenger rail service at speeds from 80 to 125 miles per hour. Higher speed passenger operations between 125 and 150 miles per hour are planned for the future. These high speed rail corridors cover some 2,600 miles and include some 2,800 public and private HRIS. The increased safety needs of passengers on future high speed trains exposed to the risks of HRIs must be addressed by HSR HRI User Services.

The National Highway System Designation Act of 1995 also recognizes the importance of improving HRI safety through ITS technology and requires that the National ITS Program Plan addresses, in a comprehensive and coordinated manner, HRI safety needs.

Many design factors must be considered in determining appropriate safety improvements at HRIs including train length, weight, speed, and frequency, number of tracks, crossing closure time, the amount and type of highway traffic, along with HRI geometries such as highway sight distance. In addition, a number of human factors and motorist behavior issues need to be addressed. For example, motorists often take inappropriate risks at crossings based on the false assumption that trains can typically stop in time to avoid an accident at the HRI. However, a typical I 00 car freight train traveling at 60 miles per hour would require more than one mile to stop, even using emergency braking. Motorists may also take risks to avoid delays at HRIs that have a history of long closures by freight trains. In addition, motorists might be confused as to how to interpret HRI warning devices that differ subtly from standard highway traffic signals. For example, the flashing red traffic light at an HHI signals motorists to stop and proceed when clear, whereas the flashing red lights at an HRI signals motorists to stop and always yield the right-of-way to trains. Furthermore there are no national regulations on motorist responses to flashing lights; each state determines its own regulations on this issue.

Standards for design, installation, and operation of current HRI warning devices are covered in the Manual on Uniform Traffic Control Devices (MUTCD) and A Policy on Geometric Design of Highways and Streets (References I and 2). However, there are no FRA regulations that mandate the type of warning devices to be provided at HRIS. There are presently two general categories of warning devices at HRJS: passive and active.

Passive warning devices are used at approximately 212,000 public and private at-grade HRIs. The national standard passive warning device is the "crossbuck", a white, "X" shaped sign with the words "RAILROAD CROSSING" in large black letters. This is the standard traffic control and regulatory device used in all states to notify motorists that they should be alert to the possibility of a train approaching or moving through the HRI. It has the same meaning as a yield sign. Railroad advance warning signs may also be installed on the highway prior to the HRI to alert the motorist of an HRI ahead.

Active warning devices are installed at HRIs where additional alerting capabilities are required. There are approximately 60,000 public and 1,000 private HRIs that have active warning devices. Factors considered in determining the need for active warning devices include type of roadway, type and volume of vehicular and railroad traffic, <u>ha7.,rdous</u> material traffic, maximum speeds of trains and vehicular traffic, pedestrian traffic, accident record, sight distance, and geometry of the HRI. Active warning devices usually include two flashing red lights mounted horizontally below the crossbuck. This traffic control and regulatory device is referred to as "Flashing Lights".

Flashing Lights may be further augmented with "Automatic Gates" that lower when a train is approaching to serve as a barrier between the train and motor vehicles on the approach lanes of the highway on each side of the HRI. These are referred to as "Two Quadrant" gates. Recently, research and limited deployment of "Four Quadrant" gates and "Median Barriers" has been made to improve safety at HRIS. Median barriers are placed along the center line of the highway for a distance of about 100 feet starting at each of the two quadrant gates. The median barriers help to prevent motorists from driving around the gate. Four quadrant gates close both the approach and opposite lanes of the highway on both sides of the crossing as a means of preventing motorists from driving around gates. These concepts are discussed in more detail in Section 1.7.4.3.

Some HRIs are located near HHIs that are controlled with standard highway traffic signals. To ensure safe movement of traffic through these intersections and the adjacent HR-I, active warning devices at the HFI often include the capability of preempting these nearby highway traffic signals.

The HSR subservice will address the special needs of trains with operating speeds in excess of 79 miles per hour. Because collisions between high speed passenger trains and highway vehicles will be more likely to result in significant casualties, it is essential that additional measures be taken to protect trains from highway traffic incursions. The FRA currently requires trains operating at speeds in excess of 79 miles per hour to be equipped with in-cab signals and recommends the following safety measures for HSR HRIS:

- For train operations from 80 to I IO miles per hour, the HRI must be grade separated, or have special signing and active warning devices including automatic gates which provide constant warning time. Automatic four quadrant gates should be considered. Train activated advance warning systems should also be considered, especially where sight distance is restricted.

- For train operations from 111 to 125 miles per hour, a waiver from current FRA Track Regulations is required. The HRI must be either grade separated or blocked. The blocking device must provide an impenetrable barrier to protect passenger trains from highway vehicle encroachment onto the HRI.

- For train operations above 125 miles per hour, all HRIs must be permanently blocked, or grade-separated.

Railroad operations are designed to reduce incidents at HRIs by minimizing HRI blockage times, and sounding train horns, where not prohibited by local authorities. Also some railroads are installing additional alerting lights on locomotives, referred to as ditch lights or crossing lights, and turning these lights on, along with the standard locomotive headlight, whenever they are moving.

Railroads control the movement of trains by train orders, time tables, manual block systems and providing visual signals to train crews (either on the wayside or in the locomotive cab) by means of wayside control systems which are activated by the presence of the train and/or other trains located ahead. These signal systems are interconnected so as to preclude the entry of two trains into the same controlled section of track. The signal may also be controlled by central dispatchers who may also be in voice contact with train crews. The railroads are conducting research and limited deployment of advanced train control systems which respond to electronic signals and have the ability to provide automated control of the train speed and braking. The advent of high speed passenger trains sharing trackage with lower speed freight trains has presented additional challenges to the design of safe and efficient train control systems.
HRI User Services are thus required to address the critical safety needs imposed by cur-rent rail operations (freight, intercity passenger, light rail, and commuter rail) over HRIs as well as additional needs created by future high speed rail passenger service. HSR User Service systems will augment and replace current HRI warning devices to effectively enhance HRI safety. The factors influencing safety at HRIs that must be dealt wit@ by HRI user service systems include risk taking behavior of drivers, train operations, track and highway characteristics, and current HRI and highway traffic control systems. The new technologies that emerge to provide HRI User Services must be proven cost effective and highly reliable before their wide-scale implementation in the highway and rail system environments. It is also critical for the improvement of HRI safety that the control and signal systems of the distinctly different highway and railroad modes be interoperable and communicate precisely with each other. The fact that approximately 50 percent of all HRI accidents occur at HRIs with today's active warning devices is compelling evidence that these systems need to be improved. It is very important, therefore, to include HRI user services in the overall national plan for deploying ITS in both the near term and long term time frames.

1.7.3 Service Description

The HRI User Service will integrate ITS technology into HRI warning systems to provide for improved control of train and highway traffic to avoid and reduce the severity of collisions at HRIS. The service helps to improve safety at HRIs by developing ITS technologies to enhance the safety effectiveness and operational efficiency of HPl safety devices. Two subservices are provided: (1) the standard speed rail (SSR) HR-1 subservice and (2) the high speed rail (HSR) HRI subservice. HRI User Services will also be applicable to the unique safety needs of highway users such as highway transit and emergency vehicle operators, motorcyclists, bicyclists, and pedestrians, as well as rail transit users such as light rail and commuter rail.

Improved train control could be accomplished by two basic functions: (1) providing advisories and alarms to train crews of HRI warning device operational status and highway vehicle intrusions onto HRIS; and (2) automated stopping of high speed (greater than 79 mph) passenger trains on designated corridors in rare emergency situations when an obstructing highway vehicle on the, HRI can be automatically detected in sufficient time to avoid a collision. The first function, crew advisories and alarms, are incorporated into the SSR subservice. The second function of automated stopping of the train is the basis of the HSR subservice and is intended primarily to address the additional safety demands of high speed passenger trains.

Improved highway traffic control could be accomplished through a variety of ITS functions available under the HRI SSR subservice. First, the HRI User Service will provide improved HRI warning devices for motorists. These improved devices will incorporate ITS technologies that will enhance their alerting capabilities, reduce their costs, and increase their performance in terms reliability, maintainability, energy use, etc. The improved HRI warning devices could also provide warnings to the motorist that are either consistent with or incorporate standard highway traffic signals making them less likely to be misinterpreted by motorists. The HRI warning devices will also include features that allow them to be integrated effectively with nearby highway traffic signal to maintain safe traffic patterns at HRIs.

In addition to HRI warning devices, the HRI User Service could provide roadside variable message signs for motorists. These message signs will effectively inform motorists of an HRI ahead and the need to exercise caution. These signs will also inform the motorist of the time to train arrival, expected delay times, and possible alternative routes to avoid excessive delays resulting from signal malfunctions or unusually long or slow trains. Furthermore, the message signs will inform the motorist if a train is already in the HRI and warn the motorist to stop.

The HRI User Service could also provide for a wide range of ITS in-vehicle motorist advisory and warning functions. The most basic function is advisory only and does not require train based information for implementation. The advisory function simply informs the driver that an HRI is ahead and caution should be exercised. The warning function will require train data and will provide the motorist with information such as the time to train arrival, the need to stop to avoid a collision with a train in the HRI, expected delay times, and possible alternative routes to avoid delays. This information could be initially provided only to priority vehicles such as school buses, ambulances, police cars, and other emergency vehicles prior to wide scale implementation. These in-vehicle HRI User Services can be particularly effective in achieving safety benefits since all passive HRIs can in essence be made active without the expense of providing them with active warning devices. In its most extended form, the in-vehicle HRI User Service can provide automated stopping of vehicles to avoid an HRI collision.

The HRI user service will also help to reduce the severity of HRI collisions by providing collision notification functions. This function would permit the rapid notification of emergency response teams in the event of an HRI incident. The capability, if train based, could be either manual (e.g., the train crew initiates the notification) or fully automated (not requiring train crew intervention). The capability, if highway vehicle based, would most likely be provided by the Automated Collision Notification User Service described elsewhere in the National ITS Program Plan.

1.7.4 Operational Concept

1.7.4.1 Overview

Long term implementation of HRI User Ser-vices could be supported through establishment of Train Control Centers (TCC) and Traffic Management Centers (TMC). In this fully deployed concept (circa 2012) of operation is for the HRI user service to provide real-time information on: train position and estimated time of arrival at HRIS, HRI status, and roadway traffic conditions at HRIS.

The HRI User Service could interface with the TCC and the train to provide HRI status to train crews and automated stopping of high speed (greater than 79 mph) passenger trains on designated corridors in rare emergency situations when a collision with an obstructing highway vehicle on the HRI can be avoided. TCCs could accomplish these train control functions through Advanced Train Control (ATC) technologies such as the Advanced Train Control System (ATCS, and the Positive Train Separation (PTS) and Positive train Control (PFC systems. These technologies are described in more detail in Section 1.7.5.

The HRI User Service will also interface with TCCs to control highway vehicle access to the HRI, provide motorists with warnings of train arrival times as a collision prevention service and to permit travelers to select alternative routes to avoid delays and minimize traffic at the HRI. Improved HRI warning devices could also provide warnings to the motorist that are either consistent with or incorporate standard highway traffic signals making them less likely to be misinterpreted by motorists. The HRI warning devices could also include features that allow them to be integrated effectively with nearby highway traffic signals to maintain safe traffic patterns at HRIS. HRI warning devices could be augmented with roadside variable message signs that provide additional warnings of a train arrival at the HRI. The HRI User Service will also provide in-vehicle visual and audible advisory and warning functions to assist motorists in avoiding collisions at HRIS. The HRI User Service could also help to reduce the severity of HRI collisions by providing collision notification functions.

It is important to note that, while this conceptual description is based on central control functions resident at TCCs and TMCS, implementation of some HRI User Services, especially early capabilities, could be accomplished with more distributed intelligence. For example, sensing, communication, processing, and control functions can take place directly between trains, HRIs, and highway vehicles to provide many HRI User Services.

1.7.4.2 Train Control Functions

The HRI User Service will provide for two levels of train control to prevent HRI collisions: (1) advisories and alarms to train crews of HRI warning device operational status and highway vehicle intrusions onto HRIs; and (2) automated stopping of high speed (greater than 79 mph) passenger trains on designated corridors in rare emergency situations when an obstructing highway vehicle on the HRl can be automatically detected in sufficient time to avoid a collision. The first function, crew advisories and alarms, apply to traditional types of rail service including freight, intercity passenger, light rail, and commuter rail, and are incorporated into the SSR subservice. The second function of automated stopping of the train is the basis of the HSR subservice and is intended primarily to address the additional safety demands of high speed passenger trains. It is not envisioned that routine freight service trains would be stopped under this user service.
The SSR and the HSR user subservices will both require information on the operational status of traffic control systems at the HRI (e.g., is the device operational, fully deployed, etc.) and whether a highway vehicle has intruded onto the HRI. Information on the operational status of traffic control systems can be obtained by HRI remote monitoring systems using appropriate sensors technologies. If a malfunction of the traffic control system is detected, this information will be communicated to the TCC and TMC. Similarly, vehicle intrusions can be detected using sensors incorporating inductive loop, radar, and video technologies. Intrusion detection systems are intended to be used only with HRI barrier systems, for example four quadrant gates, where a highway vehicle could become entrapped between the barriers. Intrusion detection systems employing video technologies can also be particularly effective in supporting efforts to enforce HRI traffic regulations by law enforcement officials.

Early implementation of the SSR subservice can be accomplished by communicating operational status of traffic control systems and vehicle intrusions directly to the crew of an approaching train as advisory and warning information for their appropriate action. Effective means of providing this information to train crew ' s and training of crews on appropriate response actions are important areas of research. The communication can be established readily by existing technologies such as cellular phone. Later stages of implementation of the SSR subservice could be accomplished by communicationof this data to the train crew through the TCC. In addition to notifying train crews for collision avoidance actions, notification of signal malfunctions can also be sent to the railroad dispatcher, signal maintainer, local police, and roadway authorities for purposes of corrective action to prevent future incidents.

The HSR subservice will provide for automated stopping of high speed (greater than 79

mph) passenger trains on designated corridors in rare emergency situations when an obstructing highway vehicle on the HRI can be automatically detected in sufficient time to avoid a collision. This function could be accomplished through communication with the TCC and the capabilities of ATC technologies such as ATCS, PTS, and PTC. The HSR subservice will verify proper operation of HRI warning devices and will detect intrusions onto HRIs employing barrier systems (e.g., four quadrant gates) to insure that there is no entrapped highway vehicle or other obstruction in the HRI. Early detection by HRI sensors of malfunctioning devices or of stalled, disabled, or trapped vehicles blocking the HRI in the path of an oncoming high speed passenger train would permit the train to be automatically stopped or slowed to prevent or reduce the severity of an HR-I collision. This function will require that HRI warning devices be activated I to 3 minutes before the arrival of a high speed passenger train. As each HRI is approached, the critical train stopping distance will be calculated based upon train operating and track approach characteristics and other factors. If the distance from the passenger train to an intruding vehicle or malfunctioning warning device exceeds the cn'tical stopping distance, automatic stopping will halt the train before an accident occurs. Ifthe distance from the passenger train to the vehicle is less than this critical stopping distance, a collision cannot be avoided, although intervention may reduce collision severity and help protect train passengers and crew.
The HSR HRI subservice provides real-time interactive coordination of highway traffic and train operations via TMCs and TCCS. These services will require information on train location, speed, weight, length, type of train (e.g., freight, high speed passenger), and type of cargo (e.g., coal, hazardous materials). It will also be necessary to detect, depending on the level of user services provided, highway vehicle location, speed, and type of vehicle. This coordination permits the TCC to improve the efficiency of train operations as well as minimize travelers' delay.

1.7.4.3 Highway Control Functions - Warning Devices

Improved highway traffic control at HRIs will be accomplished through a variety of fimctions available under the SSR subservice. The HRI active warning system's ability to control highway traffic will be improved through the use of ITS technologies that will enhance their alerting capabilities, reduce their costs, and increase their performance in terms reliability, maintainability, energy use, etc.

HRI active warning systems will be capable of adaptive signal operation to account for the train's location, direction and speed status to yield an estimate of train arrival time at the HRI and provide for constant warning times to the motorist. These systems will benefit from improved wayside or train-borne train detection technologies. Early implementation of these services can be accomplished by direct communication between the train and the HRI warning devices. Later, the required information can be enhanced through communication with TCCs and TMCS.

Four quadrant gate technologies will be developed as an improved deterrent to motorists going around gates. A significant design challenge for these systems is to develop appropriate sequencing of the entrance and exit gates and to provide for other features to prevent or minimize the risk of possible entrapment of highway vehicles.

Four quadrant gates block both lanes of the highway on each side of the HRI. If all four gates are lowered simultaneously, a motorist could pass under the gates being lowered on the near 'de of the HRI only to be blocked by the gates that have lowered on the far side of the HRI. However, delayed lowering of the gates on the exit lane of the highway on the opposite side of the HRI would provide additional time for a potentially entrapped motorist to safely exit the HRI. The exit gates could also have swing away features which would allow an entrapped motorist to break through the gate with minimal damage to his or her vehicle. Motorist awareness of this feature and ability to take advantage of it in a crisis situation are implementation issues to be addressed. Median barriers may also be used to inhibit motorists from going around gates. These barriers could be rigid or flexible to provide more or less of a physical barrier to motorists. However, these barriers could also pose an additional hazard to motorists if not properly designed.

HRI active warning systems will provide for improved integration of their operation with highway traffic control systems on adjacent roadway facilities. The improved HRI active warning systems may also incorporate red-yellow-green lights, consistent with standard highway traffic signals, to replace the flashing red lights used at HRIs today. This feature would give positive train movement information to the motorist in a manner consistent with HHIs. When current warning devices at HRIs display a "dark" indication, it means GO, while a flashing red indication means stop and always yield to the train; these messages that may not be properly understood by motorists. The use of standard highway traffic control signals may also be more cost-effective than traditional HRI warning systems.

1.7.4.4 Highway Control Functions - Variable Message Signs

Highway traffic control devices at the HRI will be supplemented with roadside variable Message signs. These messages will provide the minimum amount of information necessary for motorists (typical highway users as well as transit and emergency vehicle operators, motorcyclists, bicyclists, and pedestrians) to take appropriate safe action at HRIs. An example of the sequence of messages that could be displayed to a motorist approaching an HRI is the following:

1. "PROCEED" (HRI clear)
2. "TRAIN(S) ARRIVRNG, CLEAR THE RNTERSECTION" (30-60 seconds prior to arrival of train)
3. "STOP - DO NOT ENTER - WAIT FOR TRAIN(S) TO CLEAR CROSSING" (20-30 seconds prior to arrival of a train; other tracks verified clear if at a multiple-track crossing).
4. "TRAIN(S) WILL CLEAR CROSSRNG IN # # SECONDS and/or WATCH FOR OTHER TRARN"
5. "CAUTION" (after the train(s) clears the HRI)
6. "WAIT FOR PROCEED SIGNAL"
7. "PROCEED"

Traffic operations at intersections on adjacent roadways will be significantly improved with variable message signs that interact with the TMC and TCC. These signs can be provided real-time information about the location and arrival time of trains so that traffic can be redirected and controlled to minimize delay times that may result, for example, from signal malfunctions or unusually long or slow trains.

Information on train movements relative to HRIs can be provided to the TMC via remote systems that monitor the operational status of HRI signal systems. The TMC would be able to determine the activation status of HRI signal systems and thus monitor the progress of train movements and take action to alleviate the effects upon traffic congestion on intersecting and adjacent roadways. Possible responses might include temporary adjustment of traffic signal phasing and timing, the implementation of lane use and turn restrictions through dynamic lane assignment, and variable message signs. The information could also be relayed to emergency services personnel, police, fire, and ambulance services, to facilitate routings which avoid blocked HRIs and thereby optimize emergency response time. Similar actions could be implemented by the TMC in the event of HRI signal malfunctions.

1.7.4.5 Highway Control Functions - In-Vehicle Services

HRI User Services will include in-vehicle functions at three basic levels of interaction with the motorist (typical highway users as well as transit and emergency vehicle operators, motorcyclists, bicyclists, and pedestrians): (1) driver advisories, (2) driver warnings, and (3) automatic stopping of the highway vehicle.

In-vehicle driver advisories are the most basic service and can be accomplished without information about train operations. This ser-vice is intended to take advantage of other in-vehicle ITS user services such as En-Route Driver Information and Route Guidance. These services will basically advise the driver that an HRI is ahead and caution should be exercised. These services will require that the location of HRIs be included in their geographic data bases and that the necessary software is included to provide the advisory messages. The advisories would most likely be in the form of graphic displays as well as voice and/or alarm audible messages.

In-vehicle driver warnings will require information about train operations. These services will inform the driver of an HRI ahead and will warn the driver to take appropriate action if a train is approaching or is in the HRI. This service requires data on train location, direction, and speed. This data can be provided to the vehicle in several different ways. Early implementation of this concept could be achieved by providing the data directly to the vehicle via communications with the train or through a wayside train detector located at the HRI or along the track approach to the HRI. An advanced concept for this service would involve interaction between the vehicle, TCC, and TMC. This ser-vice concept would permit the TMC to provide train ar6val time information, expected traffic delay times, alternative routings to minimize traveler delays, and most importantly warnings to the driver to avoid collisions at the HRI. This service will also be extremely useful to highway transit vehicles and priority vehicles such as school buses and emergency vehicles to assist in avoiding collisions and responding rapidly to emergency situations. In its early stages of implementation, this service could be targeted to priority vehicles prior to wide-scale use.

The most advanced form of this service would involve automatic intervention of the in-vehicle system to stop the vehicle if a collision is imminent at an HRI. This service will require accurate data on vehicle and train dynamics as well as sensor, information processing, and vehicle control technologies. Information transmitted to the vehicle from the TMC may require augmentation with data obtained from infrastructure sensors to obtain the necessary accuracy on vehicle and train dynamics.

1.7.4.6 Automated Collision Notification

The HR-1 User Service will help to reduce the severity of HRI collisions by providing automatic collision notification functions. This function would permit the rapid notification of emergency response teams in the event of an HRI incident. The effectiveness of these response teams can be significantly improved if they have advanced information on the nature of the collision. This information can be provided by the HRI User Service by combining data on train characteristics (e.g., location of incident, train speed, train type, involvement of passengers, hazardous materials, etc.) obtained from the TCC and data on highway vehicle characteristics (e.g., type of vehicle, speed, acceleration forces, involvement of passengers and hazardous materials, etc.) obtained from the TMC. This service can be based on the train, the highway vehicle, or both. If train based, the notification to the TCC could be either manually initiated by the train crew or fully automated through the use of appropriate sensor and communication systems. The notification, if highway vehicle based, would most likely be provided by the Automated Collision Notification User Service described elsewhere in the National ITS Program Plan. The TMCs and TCCs will require integration with control centers for emergency response teams.

1.7.5 Technology

Implementation of HRI User Ser-vices will require the application of supporting technologies such as those described below.

1.7.5.1 Advanced Train Control System (ATCS)

ATCS is a microprocessor/communications/transponder-based system designed to provide both safety and business functions. Safety area capabilities are: (1) the digital transmission of track occupancy/movement authority to trains and an acknowledgment from the train crew via digital radio communications in lieu of voice communications, (2) provision of positive train separation control functions to preclude the train from exceeding its assigned limits of authority, (3) protection for maintenance-of-way and other workmen on or near rail tracks, and (4) enforcement of authorized operating speed limits for trains consistent with civil engineering and other operating constraints, including temporary slow orders. In the business related function area, ATCS enables the transmission of work order activity related to pick-ups and set-outs of individual and drafts of cars, locomotive operational status reporting, and other functions. ATCS was developed under a joint program of the Association of American Railroads and the Railway Association of Canada. A prototype ATCS installation will be made to support high speed operations on a section of the Chicago - St. Louis High Speed Rail Corridor under joint FRA/Illinois State DOT sponsorship. The PTS described below is a successor program to ATCS.

The ATCS architecture is comprised of five major sub-systems, including four information processing systems - the Central Dispatch System, the On-Board Locomotive System, the On-Board Work Vehicle System, and the Field System. The fifth major subsystem, the Data Communications System, is the "backbone" or communications platform interconnecting the four infrastructure systems and other operation and business aspects of the railroad company. System interconnection is accomplished through a combination of communication nodes, wireline and radio links

1.7.5.2 Positive Train Separation/Positive Train Control (PTSIPTC)

Positive Train Separation (PTS) and Positive Train Control (PTC) are electronic train monitoring and control systems for the next generation of train control. The two terms are often used interchangeably, though they refer to two distinct concepts. PTS provides safety enforcement through the application of technology in various subsystems that intervene to prevent trains from operating at a speed in excess of the maximum allowed, movement past any point of known obstruction or hazard, and movement beyond the limits authorized to preclude the occurrence of collisions. In many respects, PTS is a scaled-down version of ATCS, designed with ATCS safety features but lacking the more extensive business-oriented features of the full ATCS implementation. PTC also provides these features and, in addition, controls train movements to achieve more efficient operations.

Demonstration of PTS is progressing, under an agreement between the Burlington Northern Santa Fe and Union Pacific railroads, to test PTS on 800 miles of shared trackage in the Pacific Northwest region of the United States This pilot program will address the three primary safety objectives associated with PTS, namely (1) prevention of collisions between trains, (2) prevention of collisions involving trains and track maintenance personnel, and (3) prevention of 6verspeed train operation.

Railroad industry suppliers are developing train control systems to be deployed within the framework of ATCS, PTC, and PTS. One such system uses a "vital controller" to manage traffic over a limited area. It is designed to overlay on any Centralized Traffic Control (CTC) system. Another system uses inertial navigation along with positive tag readers to provide precise data to trains in CTC territory. Other suppliers are developing computer based locomotive control systems that, for example, provide the locomotive engineer with a screen to monitor and manage the train's power unit. Such systems could become components of ATCS, PTC, and PTS -

1.7.5.3 Vehicle Proximity Alerting System (VPAS)

Section 1072 of the 1991 Intermodal Surface Transportation Efficiency Act required field testing of a Vehicle Proximity Alerting System (VPAS) and comparable systems to determine their effectiveness as a safety warning device for "priority" vehicles approaching HRIS. As envisioned, the VPAS would be installed only on priority vehicles - school buses, large trucks, hazardous materials haulers, and emergency vehicles. VPAS provides an in-vehicle warning (visual and audible) to motorists at both passive and active crossings. VPAS benefits would be greatest at passive crossings where motorists currently receive no indication of an approaching train.

In July 1993, the Federal Highway Administration (FHWA) issued a request for proposals for VPAS devices to be evaluated for effectiveness as a means of improving HR-1 safety. Prototype testing by FPA of promising devices identified by FHWA occurred in 1994-1995 at the Transportation Technology Center in Pueblo, CO. The VPAS concepts evaluated employ a variety of techniques to accomplish communication from an approaching train to a highway vehicle near the HRI. The communication systems typically use radio frequency devices. Basic systems would only inform the driver that a train is approaching, or that the crossing ahead is blocked by a train, but provide no further information. Enhanced systems would inform the driver of the train's approach, direction, and estimated time of arrival at the HRI, based on train position, speed, and direction of travel data. More extensive field testing of selected VPASs will be initiated in 1996.

1.7.5.4 Geographical Mapping Systems

Many of the HRI User Services discussed require data bases of accurate information on the location of HRIs relative to highways and other related highway and rail system structures. Systems are available and are being developed for automated surveying of track and wayside infrastructure. One such system uses Global Positioning System (GPS) equipment and digital video imaging recording devices to video survey railroad facilities, including intersections of track and roadways, and provide a longitudinal-latitudinal data base. By mid-1996, the U.S. DOT/AAR Crossing Inventory data base will contain longitudinal-latitudinal data for almost all HRIs in the nation.

1.7.5.5 Other Supporting Technologies

A number of technology developments and applications need to be developed and/or enhanced and integrated to support implementation of HRI User Services in addition to those discussed above. These technologies are briefly discussed below.

- Location technologies are required to accurately position trains and highway vehicles relative to each other as well as to HRIs and other rail and highway system structures. These technologies include GPS, and inertial navigation systems, as well as various other systems for dead reckoning.

- Train detection systems are required to determine train position relative to HRIs for purposes such as activating HRI warning and control systems. Those systems which also detect train speed and direction will have more potential applications. These systems may be either train-based or infrastructure-based.

- Highway vehicle detection systems are required to determine vehicle location relative to HRIs and to determine vehicle intrusions onto HRIS. These systems, especially those employing video technologies, can support efforts to enforce traffic regulations at HRIS.

- Communication systems are required for exchanging information between trains, highway vehicles, TCC, TMC, and various rail and highway system infrastructure elements.

- Remote sensor systems are required to monitor the operational status of HPI warning and traffic control systems.

- Motorist warning and control system technologies need to be enhanced by improving their safety effectiveness, operational efficiency, and costs.

1.7.6 Potential Costs and Benefits

1.7.6.1 Potential Costs

There are about 100,000 public HRIs with passive warning devices that are candidates for warning device improvements. These improvements would be of the type included in SSR HRI User Services such as enhanced warning devices and variable message signs. Traditional active warning devices typically cost in the range of $50,000 to $150,000 per HRI. The national cost of upgrading all passive crossings with active warning devices would be prohibitive. Advances in warning device design using ITS technologies could reduce these cost. The capital and installation costs of installing active warning devices have typically been funded, since 1973, under continuing Highway Safety Acts. Since 1973 about $3 billion has been spent on upgrading about 60,000 HRIS. Railroads have typically accepted the responsibility for maintaining these new devices at a cost of about $1,300 to $2,200 per HRI per year. Since it is unrealistic to assume that all passive HRIs can be upgraded, the U.S. DOT, working with state and local agencies, will continue to prioritize HRIs for upgrading on the basis of criteria such as level of train and highway traffic, train speeds, HAZMAT traffic, etc.

A small subset of all HRIs includes the 2800 HRIs on the designated high speed rail corridors. These HRIs are candidates for improvement under the HSR HRI User Service. There is little precedent for federal funding of the types of improvement envisioned under this service. However, it is the established policy of the federal government, as expressed in Section I 0 1 0 of the Intermodal Surface Transportation Efficiency Act of 1991, to promote high speed rail service and to fund demonstration projects for improving HRI safety on the designated corridors. States, local public agencies, and railroads may be expected to share in the capital, installation, operation, and maintenance costs of HRI improvements. Costs for advanced warning and protection devices under the HSR subservice are not well established but could range from about $200,000 for a four-quadrant gate installation to about $ 1,000,000 for an energy absorbing barrier system or a low cost grade separation. The HSR subservice will also require extensive infrastructure investments on railroads to implement automatic train control systems and TCCs as well as highway system investments for TMCS. Federal subsidies for these investments might be required to achieve high speed rail passenger service on designated corridors. Much of the highway investment could be accomplished as part of a larger integrated ITS- Traffic Control User Service.

In-vehicle warning systems can address the needs of both the SSR and HSR HRI user subservices. In 1993, there were nearly 198 million registered motor vehicles in the United States, of which 146 million were automobiles. If all, or a substantial proportion, of these vehicles included HRI collision avoidance systems, the total monetary costs could be substantial. The capabilities required of these in-vehicle system, however, could be obtained as minor added functions to systems installed as part of other ITS User Services such as En-Route Driver Information and Route Guidance. The actual cost of these systems has not yet been deter-mined.

1.7.6.2 Potential Benefits

The primary benefit from HPI User Services will be a reduction in the number and severity of the 4,900 HRI collisions that occur annually. Also, the safety risk to large numbers of passengers on future high speed rail trains will be significantly reduced. Secondary benefits will result from reductions in motorist delays and improved operational efficiency of railroad and highway operations. Higher train speeds along the designated corridors will be possible creating economic and social benefits for travelers and users of rail freight transportation. These benefits will increase as ITS technologies mature, promoting the exchange of information between TMCS, TCCS, trains, and highway vehicles. Improved information exchange will support User Services such as in-vehicle navigation systems, trip planning and routing systems, and public transportation, emergency vehicle, and commercial rail and highway fleet management systems.

1.7.7 Assessment of Roles

The public safety benefits and other potential public and commercial benefits of HRI User Services are expected to be high. Therefore, the U.S. DOT will encourage joint public/private development efforts for enabling technologies. This approach, which underlies the U.S. DOT's strategy for investment in ITS technologies and systems, is used below to assess the appropriate role for the U.S. DOT in developing the HRI User Service.

The development of low speed light rail and commuter rail service as well as high speed rail ser-vice will need to be a cooperative effort between FRA, FHWA, FTA, and the involved states and local agencies. The parallel development of ITS and ATCS technologies provides a unique opportunity to integrate current and future highway and railroad traffic control systems. Due to the involvement of two significantly different modes of surface transportation, the design will be subject to regulation by highway, transit, and rail regulatory bodies.

1.7.7.1 Public Benefit

This user service addresses the most common and severe type of collision that affects railroad operations as well as the motoring public. This service therefore has high potential for public benefit. There will also be significant benefits in improving the efficiency of railroad operations as well as reducing unnecessary travel time delays, accidents, air pollution, and traveler frustration.

1.7.7.2 Potential for Private Investment in Development

This service will require significant infrastructure investment on both the highway and railroad systems. Provision of highway-based motorist warning and traffic control systems will primary be the responsibility of public transportation entities. Private industry, however, will have primary responsibility for development of train control systems. Several railroads are currently involved in joint programs with the FRA to develop and demonstrate advanced train control systems. In addition, private industry has traditionally developed HRI motorist warning devices. Companies other than traditional railroad suppliers may develop new technologies to address HRI User Service requirements. Additionally, the service may need to be designed as a capability that is integrated with other vehicle-warning devices and perhaps other ITS services as well. The market for highway infrastructure equipment will be state and local governments responsible for traffic management, while private railroad companies will develop train control systems and equipment.

1.7.7.3 Public and Private Sector Roles in HRI Deployment

The public sector role for installing, supporting, operating, and maintaining highway traffic control systems is high, since this service directly affects overall public safety and the publicly-own roadway network. State DOTs and local highway authorities have the primary role in the day-to-day operation and maintenance of traffic monitoring and control systems. The railroad Industry has traditionally assumed the responsibility for maintaining HRI warning devices. In many cases, private sector firms will have roles as contractors executing the actual design, development, and integration of the technologies and equipment to perform HRI User Services. The use of new technologies for these functions will broaden the market potential for private industry suppliers. Potential new markets for vendors of surveillance, communications, and control systems exist, and the public and private sectors may share rights-of-way for communications or other networks. In addition, private firms may also operate and maintain traffic control systems under contract to public agencies. Section 1010 of ISTEA permits Public and Private cooperative roles in the improvement of safety at HRIs to promote the implementation of high speed rail corridors. State DOTs have taken a lead role in planning the implementation of high speed rail service in their respective states.

1.7.7.4 U.S. DOT Role in Developing Service

The HRI User Ser-vice will be incorporated into the U.S. DOT National ITS Program and System Architecture. The system architecture will provide the framework for implementing the HRI User Service. The role of the U.S. DOT in developing the HRI User Ser-vice will be significant.

1.7.7.4.1 Research and Development

The U.S. DOT role in research and development activities is to address deployment issues associated with the use of advanced system components, and to develop operational concepts and support systems for advanced motorist warning and highway traffic management and train control systems. The U.S. DOT will encourage private industry involvement in the development of the necessary technology and equipment to be compatible with the functional specifications of these systems. The U.S. DOT will also work with private industry to develop functional specifications for highway and railroad traffic surveillance and control systems such that system components may be fully integrated in a-n effective and efficient manner. Section 1036(c) of ISTEA and the Swift Rail Development Act of 1994 provide funding for demonstrations of new technology in the high speed rail corridors.

1.7.7.4.2 Operational Tests

The role of the U.S. DOT in operational tests of HRI User Service systems is high. A number of current field test activities supported by the U.S. DOT are currently underway that relate to HRI User Services. These activities include:

- Prototype assessment and field testing of VPAS concepts,
- Broad Agency Announcement for innovative new technologies to address high speed rail HRI safety issues,
- Transportation Research Board's Innovations Deserving Exploratory Analysis (IDEA) Program, request for proposals on Advanced Rail Technologies,
- Next Generation High Speed Rail Program rail highway crossing hazard elimination demonstration projects,
- Four quadrant gates with intrusion detection demonstration project in Connecticut,
- Vehicle arrestor net demonstration project in Illinois,
- Friendly Mobile Barrier energy absorbing barrier system development,
- Automated wayside horn demonstration in Nebraska,
- High Speed Rail automatic train control demonstration projects in Michigan and Washington,
- Obstacle detection research, and
- Low cost grade separation demonstration in Florida.

1.7.7.4.3 Institutional and Legal

The U.S. DOT will take an active role in fostering the necessary institutional arrangements required for deployment of the HRI User Services. Liability issues have historically played an important role in influencing safety improvement decisions at HRIs. Highway traffic regulations generally require motorists to comply with HRI warning devices and to yield to train traffic. However, railroads and railroad signal suppliers are often found at fault in litigation resulting from HRI collisions. Railroads and local public authorities are therefore encouraged to improve safety at HRIs to minimize collisions and resulting litigation, but are also cautious in employing new concepts to accomplish this, as innovation may be construed as imprudent. These and other complex legal issues must be addressed within any comprehensive program to improve the safety of HRIS, in general, and, in particular, at HRIs on high speed passenger train corridors.

1.7.7.4.4 Deployment

The U.S. DOT role in deployment of this service is high to encourage adoption of advanced systems by states, local government agencies, and the railroad industry.

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GLOSSARY OF TERMS

HIGHWAY-RAIL INTERSECTION USER SERVICE

ATC	Advanced Train Control
ATCS	Advanced Train Control System
CTC	Centralized Traffic Control
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GPS	Global Positioning System
HAZMAT	Hazard Materials
HHI	Highway-Highway Intersection
HRI	Highway-Rail Intersection
HSR	High Speed Rail
IDEA	Innovations Deserving Exploratory Analysis
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
MUTCD	Manual on Uniform Traffic Control Devices
PTC	Positive Train Control
PTS	Positive Train System
SSR	Standard Speed Rail
TCC	Train Control Center
TMC	Traffic Management Center
VPAS	Vehicle Proximity Alert System